

TITLE

**PISTON-ACTIVATED VALVE AND METHODS AND APPARATUS
FOR RESTRAINING FREE PLAY IN A DEVICE**

CLAIM OF PRIORITY

This application makes reference to, incorporates the same herein by reference, and claims all benefits accruing under 35 U.S.C. § 119(e) from my application *PISTON-ACTIVATED VALVE* filed as a provisional application in the U.S. Patent and Trademark Office as U.S. application Serial No. 60/261,199, filed on January 16, 2001.

BACKGROUND OF THE INVENTION

Field of the Invention

The present invention relates to mechanical fittings and tolerancing, in particular to fittings found in shearable devices, and more particularly to pyrotechnically activated devices such as valves.

Background of the Invention

Pyrotechnic valves are commonly used in rockets for valves which must be opened reliably one time. Typically, these valves contain a seal tube which holds a pressurized gas, and this seal tube is pyrotechnically sheared to open the sealed end of the seal and start the flow of gas. The seal tube typically needs to be very strong in order to support the high gas pressure, such as by helium gas, dictated by the design. Also, initiator redundancy is typically needed to promote reliability.

Moreover, for reliability, for example, these devices are typically built with two pyrotechnic initiators for redundancy. Also, the valve typically must be able to function using only one initiator loaded to 75% or with two initiators loaded to 125%. Such valve requirements create a range of initial ballistic gas pressures with a ratio of approximately 4:1, for example. Further, peak pressures are limited by the ability of O-rings and other gas-tight fittings to contain such pressures.

One potential method of addressing the above described needs in a pyrotechnic valve is to have the piston to supply a much larger force at the beginning of stroke. This could be accomplished, for example, by either increasing the initial ballistic gas pressure or by increasing the area of the piston that is acted on by the gas. However, such pressure increase in this first potential method can be unacceptable because of a need for initiation redundancy in the device.

A second potential method of addressing the above desired needs in a pyrotechnic valve, is to increase the piston area, which can be undesirable for two reasons. First, increasing the piston area can make the piston physically large and heavy. Second, more propellant charge or possibly even an additional booster charge would be required in the initiators. These characteristics can be undesirable from a design standpoint and can generally raise the cost of the pyrotechnic valve device.

Moreover, the construction of pyrotechnic valve devices must be done to exacting tolerances. Pyrotechnic valve devices, such as those used in rocketry, for example, are often subject to considerable vibration. If there is "play" between the parts, vibrational damage can result.

SUMMARY OF THE INVENTION

It is therefore an object of the present invention to provide an improved shearable device.

1 A yet further object of the invention is to provide an improved shearable device for use with
2 pyrotechnic initiators.

3 It is further an object of the invention to provide a device which is less sensitive to vibration.

4 A still further object of the invention is to provide an improved pyrovalve.

5 These and other objects are met by the present invention. In one embodiment, the present
6 invention provides method and apparatus for preventing free play in a device, such as a pyrotechnic
valve device. An apparatus of this embodiment includes an eccentric sleeve, that is, a sleeve with
a cylindrical outer surface and a bore which is not coaxial with the outer surface. Rotation of the
eccentric sleeve adjusts the position of the bore in the eccentric sleeve, which is mated with a pin,
such as a shear pin.

In another embodiment of the present invention, the present invention provides methods and
apparatus for a device, such as a pyrotechnic valve device, the apparatus of this embodiment
including a piston which is driven to strike an object. The piston is mounted to a mount in the device
14 by a shear pin, and upon application of force, the shear pin shears and the piston moves through a
15 gap before striking the object. An apparatus of this embodiment includes: a mount; a piston adjacent
16 to the mount; the piston having a shape defining the movement direction of the piston; a shear pin
17 having an end partially inserted in a hole in the mount and another end of the shear pin connected
18 to said piston, for restraining the piston relative to the mount a hammer region formed on an end of
19 the piston located in the direction of motion of the piston, and a strikable part mounted in the
20 direction of motion of the piston from the hammer region and separated from the hammer region by
21 a gap. The other end of the shear pin is, in one alternative embodiment, connected to the shear pin

1 through a sleeve, such as an eccentric sleeve. In another alternative embodiment, the shear pin is
2 positioned in spaced relation from the strikable part in the direction of motion of the piston. In a
3 further embodiment an end of the shear pin is press fit into the mount.

4 Also, embodiments of the invention as a pyrovalve are also described. In an embodiment
5 the pyrovalve, includes: a housing having a cylindrical bore; a pyrotechnic initiator mounted in an
6 upper portion of the housing; a seal tube mounted in an extending out from the housing, the seal tube
7 having a generally cylindrical configuration and the axis of the seal tube being positioned
8 perpendicular to the axis of the bore of said housing, the seal tube further including a shearable cap
9 on the end of said seal tube inside the housing; a piston located inside in the bore of the housing so
10 as to define a direction of motion, the piston including: a flowpath formed perpendicular to the
11 direction of motion defined by the piston; a hollow formed in a side of the piston, further from the
12 pyrotechnic initiator than the flowpath, and shaped to enclose the shearable cap, the hollow being
13 larger in cross-section than the shearable cap so as to define a gap between an overhang of the piston
14 and the shearable cap; and a shear pin connecting the shearable cap to the piston through a sleeve,
15 for restraining play in said piston. Desirably, the sleeve is an eccentric sleeve.

16 BRIEF DESCRIPTION OF THE DRAWINGS

17 A more complete appreciation of the invention, and many of the attendant advantages,
18 thereof, will be readily apparent as the same becomes better understood by reference to the following
19 detailed description when considered in conjunction with the accompanying drawings in which like
20 reference symbols indicate the same or similar components, wherein:

1 Figure 1A is an embodiment of the present invention in the form of a pyrotechnically
2 activated valve, seen in cross-section before activation of the valve;

3 Figure 1B is a view of the pyrotechnically activated valve of Figure 1A shown after
4 activation of the valve;

5 Figure 2 is a cross-section of the valve shown in Figure 1A, prior to activation of the valve,
6 taken across the line labeled "2" of Figure 1A and the line "2" of Figure 6B;

7 Figure 3A is a cross-sectional view of a device, such as can be used in a valve device,
8 illustrating a general embodiment of the invention incorporating an eccentric sleeve;

9 Figure 3B is a plan view taken from the bottom of the device of Figure 3;

10 Figures 4A and 4B are a cross-sectional views of a device illustrating another general
11 embodiment of a device of the invention, respectively before and after actuation of the device, such
12 as a valve device;

13 Figure 5 is a close up of a portion to illustrate the shear pin area of the valve device shown
14 in Figure 1A;

15 Figures 6A-6F are a series of views of the valve device shown in Figures 1A and 1B, with
16 Figure 6A illustrating an external side view of the valve shown in sectional view in Figures 1A and
17 1B along the section line "1A /1B", with Figure 6B illustrating an external front view of the valve
18 of Figures 1A and 1B with the sectional view of Figure 2 taken along line "2" and with the sectional
19 view of Figure 6F taken along the line "6F", with Figure 6C illustrating a right side view of the valve
20 of Figures 1A and 1B, with Figure 6D illustrating a top external view of the valve of Figures 1A and
21 1B, with Figure 6E illustrating a bottom external view of the valve of Figures 1A and 1B, and with

1 Figure 6F illustrating a partial sectional view of the valve of Figures 1A and 1B of Figure 6B along
2 the sectional line "6F" of Figure 6B;

3 Figures 7A-7C are a series of views of the eccentric sleeve of the valve device shown in
4 Figures 1A and 1B, with Figure 7A illustrating a left side external view of the sleeve of Figures 1A
5 and 1B, with Figure 7B illustrating a sectional view of the sleeve of Figure 7A taken along the
6 section line "7B" of Figure 7A, and with Figure 7C illustrating a right side external view of the
sleeve of Figures 1A and 1B; and

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14 Figures 8A-8I are a series of views of the piston of the valve device shown in Figures 1A and
15 1B, with Figure 8A illustrating a front external view of the piston of Figures 1A and 1B, with Figure
16 8B illustrating a right side external view of the piston of Figures 1A and 1B, with Figure 8C
17 illustrating a left side external view of the piston of Figures 1A and 1B, with Figure 8D illustrating
18 a cross-sectional view of the piston of Figures 1A and 1B illustrated in Figure 8C taken along line
19 "8D" of Figure 8C, with Figure 8E illustrating a sectional view of the piston of Figures 1A and 1B
illustrated in Figure 8D taken along line "8E" of Figure 8D, with Figure 8F illustrating a top view
of the piston of Figures 1A and 1B, with Figure 8G illustrating a detail view of an O-ring groove on
the piston of Figures 1A and 1B as defined by the view illustrated in Figure 8C, with Figure 8H
illustrating a sectional view of the piston of Figures 1A and 1B illustrated in Fig 8D taken along the
line "8H" of Figure 8D, and with Figure 8I illustrating a bottom view of the piston of Figures 1A and
1B.

20 DETAILED DESCRIPTION OF THE INVENTION

1 An embodiment of a valve device of the present invention is a pyrovalve, that is, a
2 pyrotechnically activated valve. Pyrovalves can be used, for example, in rockets for valves which
3 are activated only once. For example, a pyrovalve can be a normally closed valve mounted in
4 proximity to a main rocket motor. The valve can be installed in a flow path between a pressurized
5 helium tank and the interior of the main motor, for example. During the first phase of flight, the
6 main motor burns to provide propulsion. During this time, the valve remains in the normally closed
position, preventing the flow of helium to the motor. When the main rocket motor burns out, the
valve is actuated to provide a helium purge to the motor. This brings the motor rapidly to a zero
thrust permitting stage separation shortly thereafter.

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13 An embodiment of a valve device of the present invention as a pyrovalve is shown in Figures
1A, 1B, 2, 5, 6A-6F, 7A-7C and 8A-8I, with Figure 1A illustrating the pyrovalve in the pyrovalve's
normally closed position prior to activation. Referring to Figures 1A, 1B, 2, 5, 6A-6F, 7A-7C and
8A-8I, in this embodiment, the pyrovalve is designed to be installed connected to a gas source at the
14 right side in the figure 1A, at "inlet fitting" I. The inlet fitting I leads to seal tube 2, which is
15 generally machined from a solid material, such as a precipitation hardened stainless steel, with no
16 outlet, to block the flow of gas through the pyrovalve. At an end of seal tube 2 is a shearable cap
17 30, which is an integral part of seal tube 2, the shearable cap being formed of the material of the seal
18 tube 2, such as a precipitation hardened stainless steel. Groove 40 in seal tube 2 "necks down" the
19 seal tube 2, and is generally formed by machining. This necking down allows the shearable cap 30
20 to be mechanically sheared when the pyrovalve is actuated, but to withstand the gas pressure of the
21 gas source, such as a helium gas source, prior to shearing. For example, in an actual embodiment

1 of a pyrovalve, the seal tube 2 has been designed to withstand internal gas pressures in excess of
2 12,000 pound per square inch, but shearable cap 30 shears off at a ballistic pressure in the vicinity
3 of 4,000 pounds per square inch to open the flow path F when required. After actuation, the gas,
4 such as helium, will flow from right to left toward the "Outlet Fitting" O in the pyrovalve.

5 Continuing with reference to Figures 1A, 1B, 2, 5, 6A-6F, 7A-7C and 8A-8I, within housing
6 1 of the pyrovalve is, piston 3 being formed of a precipitation hardened stainless steel, for example.
Piston 3 is also shown in greater detail in Figures 8A-8I. The piston 3 can be cylindrical in shape.
Piston 3 can be seen in Figures 1A and 2 to have an upper flowpath 45, which becomes the gas
flowpath F after activation of the pyrovalve. Piston 3 also has lower portion 3a which has a hollow
region surrounding shearable cap 30. The hollow region is shaped to provide a gap 37 above
shearable cap 30, and a portion of the piston 3 between flowpath 45 and the hollow region forming
as overhang or hammer region 35, since overhang 35 appears to overhang the shearable cap 30 as
seen in Figures 1A and 2.

14 Referring again to Figures 1A, 1B, 2, 5, 6A-6F, 7A-7C and 8A-8I, mounted in the end of seal
15 tube 2 and extending away from the seal tube is a shear pin 5, shear pin 5 being formed of any
16 suitable fractureable material, such as aluminum, for example. Shear pin 5 is installed in the bore 18a
17 of sleeve 18. The outside of sleeve 18 is cylindrical in shape, and sleeve 18 has a cylindrical bore
18 18a which is parallel to but not coaxial with the outside of the sleeve 18. Thus, sleeve 18 has an
19 eccentric bore 18a. Sleeve 18 is shown in greater detail in Figures 7A-7C. The outside of sleeve
20 18 is mounted in a bore 3b in piston 3. Set screws 20 pass through a portion of the piston 3 and
21 contact the outside of sleeve 18. Also, the axis Z1 of the seal tube 2 is desirably positioned

perpendicular to the axis Z2 of the bore 1a of the housing 1, as illustrated in Figure 1A, for example.

Also shown in Figures 1A and 2 are O-rings 7, seal 19 and ball bearing or ball member 21 and lock plug 4. Also shown is Faraday cap 15, present before installation to prevent accidental discharge of the initiators 16.

In order to activate the pyrovalve, a sufficient amount of electric current is applied to one or both of electrical initiators 16. These pyrotechnic initiators produce hot pressurized gas, which are the products of combustion of the pyrotechnic materials contained within them, in the cavity C over piston 3. Gas within this cavity C is sealed by O-rings 7. The pressure, acting over the area of the piston 3, produces a force to drive the piston 3 downward as shown in the Figures, such as Figures 1A and 1B. The motion of the piston 3 is resisted by the shear pin 5, which is held in place by seal tube 2, a portion of the shear pin 5 being held snugly in the seal tube 2, such as by being press fit into the seal tube 2. The shear pin 5 is designed to shear across the plane where shearable cap 30 at the left side of seal tube 2 mates with piston 3. In this particular design, the force to shear the shear pin 5 is nominally around 1,600 pounds. The shear pin 5 is designed to shear off at a lower force than is necessary for the shearing of shearable cap 30 from seal tube 2. For example, in this particular design, the shearable cap 30 requires a shear force of approximately 4,000 pounds to shear.

When the force produced by the gas is sufficient, shear pin 5 shears and piston 3 begins to travel downward in the direction of arrow D of Figure 1B. Since the shear pin 5 is designed to shear more easily than the shearable cap 30, the shear pin 5 shears off before shearable cap 30 at the end of the seal tube 2. That is, piston 3 begins to move before the flow path F opens. After shear pin 5 shears, the piston 3 accelerates downward in the direction of arrow D, building up kinetic energy

1 until overhang or hammer region 35 in the piston 3 strikes the shearable cap 30, the shearable cap
2 30 designed to be sheared off from the seal tube 2. For example, in the specific example shown, the
3 piston 3 travels approximately 1/4 inch before striking the shearable cap 30. At this point, the
4 kinetic energy of the moving piston 3 is well in excess of the energy required to shear off the end
5 of the seal tube 2.

6 During the portion of the stroke that the piston 3 is shearing off the shearable cap 30, the
piston 3 will generally temporarily slow down. Piston kinetic energy is partially depleted and used
as shear energy. The piston 3 then accelerates as a result of the expanding ballistic gas still acting
on the piston 3. At the end of the piston stroke a skirt 50 which is machined into the piston 3 flares
out into a conical cavity 51 formed by the space between the lock plug 4 and housing 1, the lock
plug 4 and housing 1 being made of precipitation hardened stainless steel, for example. The lock
provided by the skirt 50 flaring out into the conical cavity 51 both holds the piston 3 permanently
in the final position P and gently slows the piston 3, minimizing shock. In the final position P,
14 illustrated in Figure 1B, the final lock is engaged and the skirt 50 of piston 3 is in a flared position
15 in over the lock plug 4. Also, in the final position P, the shearable cap 30 of the seal tube 2 and the
16 portion of shear pin 5 in the shearable cap 30 are restrained in a portion of the cavity 51 of Figure
17 1A at or near position S illustrated in Figure 1B.

18 When actuated, as shown in Figure 1B, shear pin 5 can be seen to be broken into pieces 5a
19 and 5b as illustrated in Figure 1B. Piece 5b is retained in shearable cap 30, which has been sheared
20 from seal tube 2.

21 A valve such as that shown in Figures 1A and 1B is typically required to survive a very high-

1 level shock and random vibration environments, such as during the period of time between launch
2 and the actuation of the valve. These environments can be particularly brutal on internal
3 components that have any "free play". This free play can allow impact loads on internal components
4 that rapidly cause damage. The valve of the present invention, such as the valve device of Figures
5 1A and 1B, incorporates a design to minimize such free play, which is described more generally in
6 Figures 3A and 3B.

7 Referring now to Figures 3A and 3B. In Figure 3A, an embodiment of a device of the
8 present invention such as can be used in a valve device, to minimize free play is shown having part
9 303 and part 310, where parts 303 and 310 are to be connected so as to avoid free play in the
10 directions shown in double headed arrow 320. Part 303 has a cylindrical bore 303a in which sleeve
11 318 is fitted. Sleeve 318 has a cylindrical outer surface which fits snugly into the bore 303a in part
12 303. Sleeve 318 also has a cylindrical bore 318a which is parallel to, but not coaxial with, the outer
13 cylindrical axis of sleeve 318. That is, sleeve 318 has an eccentric bore 318a. Pin 305, such as a
14 shear pin or any shearable feature of part 310, extends from part 310. Pin 305 is cylindrical and fits
15 snugly into the bore of sleeve 318.

16 In using the device of the present invention of Figures 3A and 3B, sleeve 318 is rotated
17 within the bore 303a in part 303. As seen in Figure 3B, since sleeve 318 is eccentric, rotation of
18 sleeve 318 would cause the bore 318a in sleeve 318 to rotate around the axis A of the bore 303a in
19 part 303, and this allows for negligible variation in the position of pin 305 in the direction of arrow
20 320, but sufficient variation in the lateral direction L, as indicated by the double-headed arrow L in
21 Figure 3B, to allow assembly of parts manufactured to reasonably large tolerances.

1 The device of Figures 3A and 3B can also include a securing means, such as a set screw 320.

2 After pin 305 is inserted into sleeve 318, set screw 320 would be tightened to lock and possibly
3 deform sleeve 318, thus locking the position of pin 305 with no or minimal free play.

4 This general design of a device for minimizing free play of Figures 3A and 3B is
5 incorporated into the pyrotechnic valve shown in Figures 1A and 1B. In the pyrotechnic valve of
6 Figures 1A and 1B, the piston 3 has to be contained due to the vibration of the environment during
7 use. Free play of 0.010 to 0.020 inches, for example, would lead to impact loads which would
8 destroy the shear pin. Thus, in the design of a device for minimizing free play incorporated and
9 shown in Figure 1A, one end of shear pin 5 is press fit into shearable cap 30 of seal tube 2. Also, the
10 pin 305 can be integrally formed as a part of part 310, as illustrated in Figure 3A, for example.
11 Sleeve 18 is incorporated to slip fit into bore 3a of piston 3. The eccentric design of sleeve 18 allows
12 alignment of shear pin 5 into sleeve 18 by rotation of the sleeve 18, thereby avoiding or minimizing
13 free play in the connection of shear pin 5 to piston 3, thereby reducing any free play such as to only
14 approximately 0.001 to 0.002 inches, for example. Set screws 20 in conjunction with ball bearing
15 21 or ball member as the securing means further lock and deform sleeve 18 and further prevent or
16 further minimize any free play.

17 The valve shown in Figure 1A and 1B also incorporates a design which allows the piston 3
18 to gather momentum before striking the shearable cap 30, as can be used in conjunction with the
19 sleeve 318 of Figures 3A and 3B, as described above. A type of this design is described more
20 generally with reference to a general embodiment of the present invention shown in Figures 4A and
21 4B.

1 Referring to Figures 4A and 4B, in Figure 4A, a device is shown including mount 410 and
2 piston 403. Mount 410 can be a cylinder in which piston 403 rides, or can more generally be any
3 part providing a guide surface for the downward motion of the piston 403. Likewise, piston 403 may
4 be a cylindrical piston, or can be of any of a variety of shapes which can travel downward in the
5 direction of the arrows indicating a propelling force 460 as shown in the Figures 4A and 4B. Piston
6 403 is mounted to mount 410 by shear pin 405, which is inserted in holes or apertures 410a and 403a
respectively in mount 410 and piston 403.

Continuing with reference to Figures 4A and 4B, the lower part of piston 403 has hammer
surface or hammer region 435 which is designed to deliver a blow to strikable part or shearable
element 430 when the piston 403 moves. Here, part 430 can be any part to be struck. There is a gap
470 between the hammer surface 435 of the piston 403 and the shearable element 435.

In the particular embodiment illustrated in Figures 4A and 4B, strikable part 430 or shearable
element 430 is attached to a stationary part 440. As illustrated in Figures 4A and 4B, stationary part
14 440 is mounted to mount 410, but stationary part 440 could be mounted to anything stationary
15 relative to the piston 403. Also, as shown in Fig. 4A, piston 403 can have a ledge 445 which is not
16 aligned with hammer surface 435.

17 In operation, a propelling force 460 indicated by the arrows in Figures 4A and 4B is applied
18 to the top of piston 403. This propelling force can be gas pressure, pneumatic pressure, an electric
19 or mechanical force, etc. When the force reaches a certain value, shear pin 405 which can be spaced
20 from the shearable element 430 in the direction of travel or motion of the piston 403, as illustrated
21 in Figure 4A, shears and the piston 403 moves downward in the direction of the arrows 460

1 indicating the propelling force in Figures 4A and 4B. Alternatively, when the mount corresponds
2 to a seal tube, such as seal tube 2 of Figures 1A and 1B, the pin 405 can be press fit into the
3 shearable cap 30 of the seal tube 2, as described previously with respect to Figures 1A and 1B.
4 Piston 403 moves through gap 470 before hitting the strikable part of shearable element 430; and
5 thus, piston 403 is able to gather momentum before the impact with the strikable part or shearable
6 element 430. When used as a valve device, such as illustrated in Figures 1A and 1B, the shearing
of the shearable element 430 would typically create a flow path G formed integrally as a passage in
the piston 403, the location of the flow path G being indicated in Figure 4B.

In the particular embodiment shown of Figures 4A and 4B, the strikable part or shearable
element 430 shears off of stationary part 440 upon impact at a shearable link 430a connecting the
strikable part or shearable element 430 and the stationary part 440. Due to the ledge 445, the
stationary part 440 is not hit by the piston 403 when shearable element 430 is impacted by the piston
403. Stationary part 440 can thus serve as a detent for stopping the downward motion of the piston
403. In such a case, the total stroke of the piston 403 is given by gap 450 illustrated in Figure 4A.
In general, there will be some sort of a detent for stopping the piston after it has hit the object to be
worked.

Although shown in Figures 4A and 4B for a shearable object, the device of the present
invention illustrated in Figs 4A and 4B is applicable to any object to be struck. For example, hammer
surface or hammer region 435 could be striking a rivet or nail, punching a hole, making an
impression, etc., for example.

In the pyrovalve embodiment shown in Figures 1A and 1B, however, piston 3 is mounted

1 through shear pin 5 to shearable cap 30 which is part of seal tube 2, which is held in place by the
2 housing 1 and the shear pin 5 is not initially spaced from the shearable cap 30 in the direction of
3 travel or motion of the piston 3. Upon activation, the piston 3 moves downward, and overhang 35
4 moves through gap 37 before striking shearable cap 30. In the invention as shown in Figures 1A and
5 1B, the interaction of skirt 50 with the conical cavity formed by the space between the lock plug 4
6 and housing 1 serves as the detent.

7 In the pyrovalve of the invention, the piston design, incorporating the sleeve design to
8 minimize free play, allows the piston to gain momentum before striking the shearable cap. One
9 result of this design is that less of the pyrotechnic explosive is required to shear the cap than in a
10 comparable design with no shear pin in which the piston initially contacts the shearable cap.

11 While there have been illustrated and described what are considered to be preferred
12 embodiments of the present invention, it will be understood by those skilled in the art that various
13 changes and modifications may be made, and equivalents may be substituted for elements thereof
14 without departing from the true scope of the present invention. In addition, many modifications may
15 be made to adapt a particular situation to the teaching of the present invention without departing
16 from the scope thereof. Therefore, it is intended that the present invention not be limited to the
17 particular embodiments disclosed as the best mode contemplated for carrying out the present
18 invention, but that the present invention includes all embodiments falling within the scope of the
19 appended claims.